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Implementation of a test rig to characterize the process suitability of filaments for 3D printing

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Abstract: 3D printing is of growing importance in medical engineering. While the use of new types of filaments expands the range of applications, an answer to the question whether the new materials can be processed well requires time-intensive testing on actual printers. Consequently, the need has emerged to be able to check such potentially processible materials before the start of a print. For this purpose, a prototypical test stand was developed, replicating the process of a conventional 3D printer. With this setup, filaments can be extruded at specific temperatures and speeds. Furthermore, the feed force is measured while speed and temperature are iterated. The measurements obtained in this way can be visualized and exported.

I. Introduction

In the following, the test rig and its benefits are presented in brief. Furthermore, the measuring results are interpreted.

I.I. Basic function

The test rig called *FilVer* (Filament Verification) implements an extrusion line of a conventional 3D filament printer in which the typical key components can be found. First and foremost, it includes the feeder which conveys the filament with the help of a pinch roller mechanism, and furthermore, the nozzle unit consisting of the hot and cold end. The self-developed control unit offers the possibility to determine the parameters temperature and extrusion rate and provides a graphical display of the results. The graph shows a curve of the feed force measured over the different extrusion rates (feed rates). Using this curve, the viscosity of the material can be determined within the real process. The basic principle is comparable to that applied in the measurement of the melt flow index (MFI). A correlation could be established between the data and the printing quality. By data comparisons or the use of a reference curve of a known material, the optimized printing parameters can be determined time-efficiently. In terms of materials science, this allows different compositions to be easily compared during material development so as to gain early clarity about promising compounds.

I.II. Viscosity and printing quality

Printing quality and in-nozzle viscosity correlate closely. If the melt is too liquid, it continues to flow after exiting the nozzle, so that the print quality is drastically reduced. In addition, retract movements are strongly restricted in their effect of preventing material oozing out of the nozzle when it relocates during printing moves. If, on the other hand, the melt is too viscous, the feeder can no longer apply the required force and the extrusion stops. By knowing the maximum feed force of the system, the minimum processing temperature to achieve the best printing quality can be determined using the *FilVer*.

Figure 1: View of the FilVer. The control unit is visible in the front. At the back behind it is the extrusion path with the integrated force measuring unit.

I.III. Measuring sequence

The control unit guides the user through the process, starting with the setting of parameters, e.g. the number of measurements and the feed rate bandwidth. When the run starts, the nozzle temperature, the stepper motor for the filament feeding and the measuring process are automatically controlled by the control panel. After the heating up of the nozzle, the extrusion commences at the first defined feed rate. The self-developed force measuring unit measures the feed force. The feed rate consecutively increases to the defined maximum at adjustable intervals. At each step, the feed force is measured and graphically displayed. At the end of the run, the dataset can be named and exported to an SD card for further evaluation.

II. Application

To illustrate the benefits of the experiment, an improvable PLA filament was used to show how the printing parameters can be optimized with the *FilVer* to achieve significantly better results. In a first run, the reference curve of a well-known PLA filament can be plotted at its given printing temperature. In a second run it is now possible to optimize the problematic material and adapt it to the reference curve. When the reference curve is reached, the same viscosity of the melt can be assumed.

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This procedure allows to investigate and adapt materials with regard to optimized printing parameters. The following graph (Figure 2) shows the results of the optimization process of an improvable PLA filament, which suffers from poor printing quality at the temperatures specified by the manufacturer. In general, the required feed force increases with higher feed rates. The problematic material was first examined at 210°C. It was observed that the feed force was lower than that of the reference material. The melt was less viscous. In printing tests, the poor printing quality at this temperature setting was proven. The characteristic curves of this material at 200 and 190 °C were then recorded with the *FilVer*. At 190 °C, the characteristic curve approaches the reference curve showing that the in-nozzle viscosities of the melt are comparable. The printing tests demonstrated a significantly improved printing quality equivalent to that of the reference material.

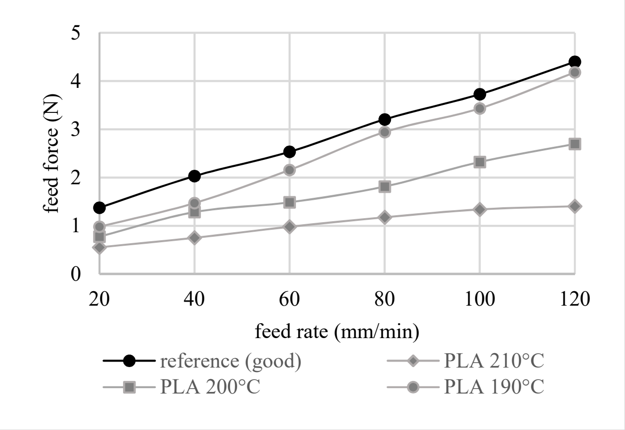

Figure 2: Optimization process based on the reference curve of a well-known material

Another application scenario is a comparison of filament compositions. Differences in the printing capability can be derived from the characteristic curves allowing a conclusion on the melting behavior in the nozzle at different feed rates and temperatures. Furthermore, it is possible to determine the printing speeds that can be achieved in terms of the maximum feed force of the feeder. In Figure 3, different formulations of a thermoplastic elastomer (TPE) are investigated at the same temperature.

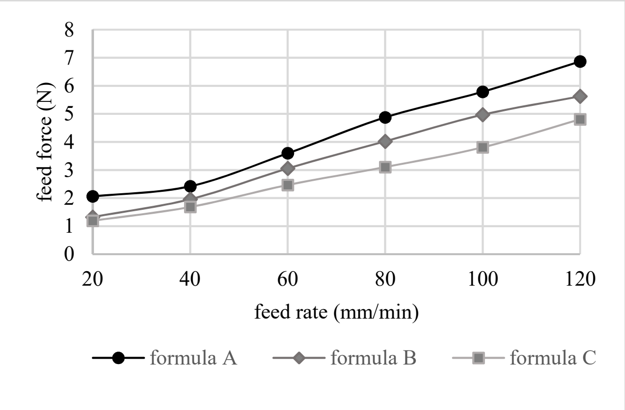

Figure 3: Curve array. Different TPE recipes compared at same temperature (240°)

The resulting differences can be interpreted as different behaviors of the melt within the nozzle. In this way, the process parameters and the suitability of the recipes can be investigated.

III. Results and discussion

It must be said in advance that for a successful printing further parameters, the source files and the mechanical qualities of a 3D printer are important. However, the printing quality seems to correlate directly with the viscosity of the melt, which is why the *FilVer* brings advantages in material and printing optimization. The developed measuring electronics and force measurement unit deliver measured values with an error of 3%. The friction losses during measurement are negligible and are in a smaller order of magnitude than the measured feed forces. The measurement series are well reproducible. The ability to quickly convert the experiment setup to other nozzles and feeders allows the adaptation to different 3D printing processes and specific 3D printers.

IV. Conclusions

With the increasing use of additive manufacturing in the medical sector, the choice and development of materials will become more important [1]. Assuming the same printing temperature for all formulations of a master batch during material research, non-ideal printing parameters for individual recipes will result in incorrect prints, since the respective materials are not applied within their optimum parameters. If test bodies are printed with suboptimal settings, the resulting findings could lead to material developments in the wrong direction. The result may be costly misdevelopments. Such risks can be reduced with the help of the *FilVer*. Furthermore, information can be obtained on the ideal printing temperature and printing speed. This applies in particular regarding good printing quality (low melt viscosity) and compliance with maximum feed force values in order to avoid feeder overloading. With the help of the knowledge gained from the tests, reliability in printing can be increased as filament slippage can be ruled out by setting the correct feed force. If fast printing is required, a maximum feed rate that functions reliably can be determined from an economic point of view [2]. Compromises in speed and printing quality can be investigated. However, it should be noted, that other printing parameters play a role for the end result.

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AUTHOR'S STATEMENT

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REFERENCES

[1] R. Lachmayer, R.B. Lippert, T. Fahlbusch, *3D-Druck beleuchtet (book),* Springer Vieweg Verlag, 2016, pp. 10-11

[2] C. Feldmann, C. Schulz, S. Fernstörning, *Digitale Geschäftsmodell-Innovationen mit 3D Druck (book)*, Springer Gabler Verlag, 2019, pp. 11-13